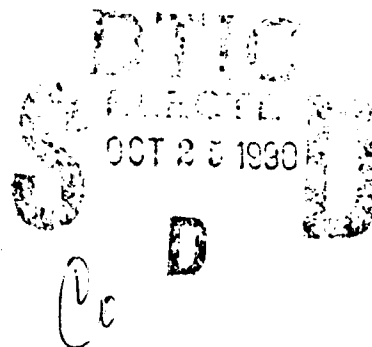


A Shallow Water Range Dependent Acoustic Propagation Problem With a Stepwise Coupled Mode Solution

**A Paper Presented at the
113th Meeting of the Acoustical Society of America,
11-15 May 1987, Indianapolis, Indiana**

**Richard B. Evans
ODSI Defense Systems, Inc.**

**James M. Syck
Surface Ship Sonar Department**



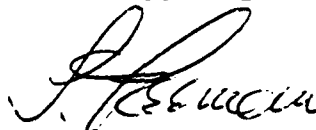
**Naval Underwater Systems Center
Newport, Rhode Island / New London, Connecticut**

AD-A227 791

PREFACE

The work reported in this document was completed under NUSC Project No. A60600, Dr. William Carey and Dr. James Syck, Co-Principal Investigators.

REVIEWED AND APPROVED: 29 September 1987

A handwritten signature in dark ink, appearing to read 'L. Freeman', is positioned above the printed name.

L. FREEMAN

HEAD: SURFACE SHIP SONAR DEPARTMENT

The authors of this document are located at ODSI Defense Systems, Inc., North Stonington, CT, and the New London Laboratory, Naval Underwater Systems Center, New London, CT 06320.

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REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED			1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for Public Release; Distribution Unlimited	
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE				
4. PERFORMING ORGANIZATION REPORT NUMBER(S) TD 8057			5. MONITORING ORGANIZATION REPORT NUMBER(S)	
6a. NAME OF PERFORMING ORGANIZATION Naval Underwater Systems Center		6b. OFFICE SYMBOL (If applicable) 3331	7a. NAME OF MONITORING ORGANIZATION	
6c. ADDRESS (City, State, and ZIP Code) New London Laboratory New London, CT 06320			7b. ADDRESS (City, State, and ZIP Code)	
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Naval Underwater Sys. Ctr.		8b. OFFICE SYMBOL (If applicable) 3331	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
8c. ADDRESS (City, State, and ZIP Code) New London Laboratory New London, CT 06320			10. SOURCE OF FUNDING NUMBERS	
			PROGRAM ELEMENT NO.	PROJECT NO. A60600
			TASK NO.	WORK UNIT ACCESSION NO.
11. TITLE (Include Security Classification) A SHALLOW WATER RANGE DEPENDENT ACOUSTIC PROPAGATION PROBLEM WITH A STEPWISE COUPLED MODE SOLUTION				
12. PERSONAL AUTHOR(S) Richard B. Evans and James Syck				
13a. TYPE OF REPORT Summary		13b. TIME COVERED FROM TO	14. DATE OF REPORT (Year, Month, Day) 1987 Sept. 29	15. PAGE COUNT 13
16. SUPPLEMENTARY NOTATION				
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP		
			Propagation Models, Couple, Parabolic Equation	
19. ABSTRACT (Continue on reverse if necessary and identify by block number) A particular shallow water range dependent environment was chosen and the stepwise coupled mode model COUPLE was applied. The problem consisted of a refracting water layer overlying an isospeed liquid sediment. The water depth varied between 120 m and 210 m over a range of 50 km. The calculations were done at 50 and 300 Hz. The main range dependent effect considered was the redistribution of energy due to forward and backscatter caused by both large and small scale bathymetric changes. The large scale changes, that evolve slowly with range, produced a smooth transition of energy between different sized sets of locally propagating modes. The more rapid, small scale, changes caused a pronounced energy loss due to forward scattering into highly attenuated high angle modes. The effects of backscatter were negligible. The results are compared in this paper to IFD/PE and, in a subsequent paper, with other parabolic equation models.				
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED	
22a. NAME OF RESPONSIBLE INDIVIDUAL JAMES SYCK			22b. TELEPHONE (Include Area Code) (203) 440-5999	22c. OFFICE SYMBOL 3331

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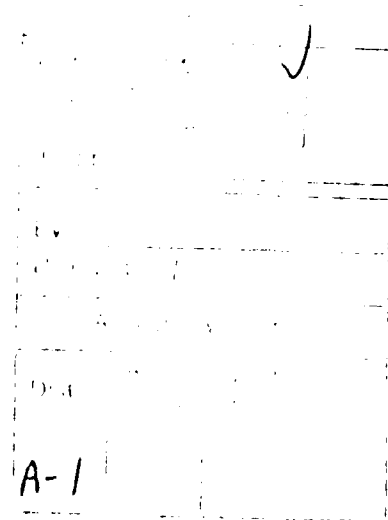
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A SHALLOW WATER RANGE DEPENDENT ACOUSTIC PROPAGATION PROBLEM
WITH A STEPWISE COUPLED MODE SOLUTION

INTRODUCTION

We present a sequence of range dependent calculations done with COUPLE and IFD/PE. We comment on the dominant range dependent effects. Some of these calculations show also perfect agreement between the two models. This provides a benchmark test case for other range dependent models.

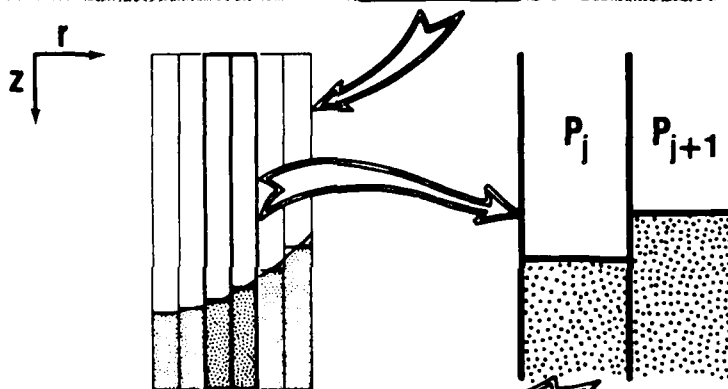
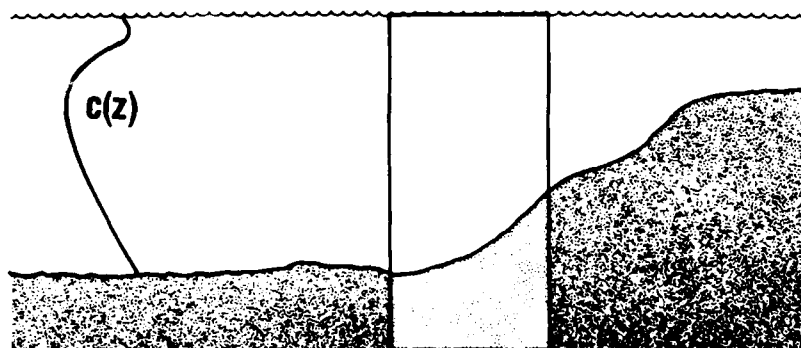


VIEWGRAPH 1: MODELS

COUPLE is a stepwise coupled mode model. It was developed by R. Evans and K. Gilbert at NORDA. The basis of the calculation is shown in viewgraph 1. The environment is discretized into locally flat regions. In each of these locally flat regions, the field is expanded as a sum of local modes. Matching the fields in adjacent regions, along a vertical interface, yields a linear relation between the unknown expansion coefficients in adjoining regions. The set of all such linear equations is solved for the expansion coefficients. The recent application of the decoupling algorithm has made this numerically practical in a wide range of problems.

IFD/PE is an implicit finite different algorithm applied to the parabolic approximation of the elliptic wave equation. It was developed for ocean acoustics by D. Lee and G. Botseas at NUSC.

STEPWISE COUPLED MODES



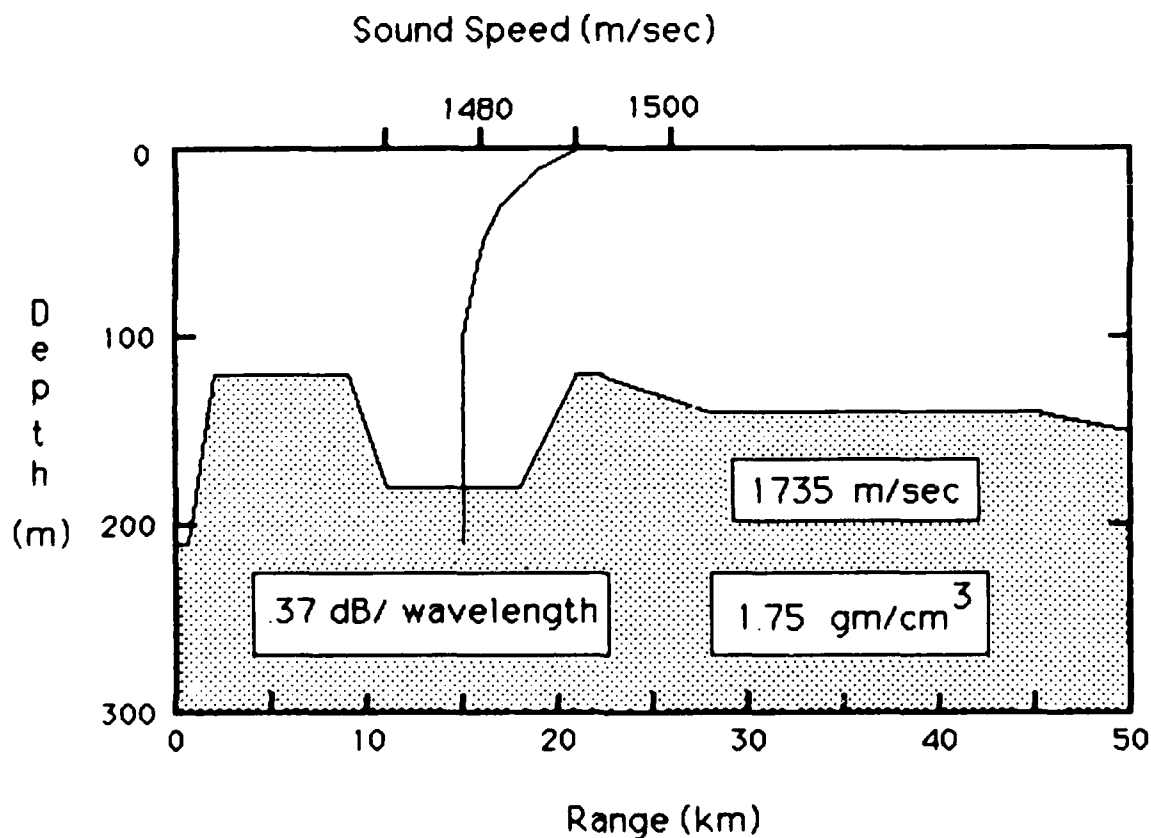
$$P_j(r, z) = \sum_{m=1}^M \left[a_{j,m} \frac{e^{ik_{j,m}r}}{(k_{j,m}r)^{1/2}} + b_{j,m} \frac{e^{-ik_{j,m}r}}{(k_{j,m}r)^{1/2}} \right] \phi(z, k_{j,m})$$

$$\begin{bmatrix} \vec{a}_{j+1} \\ \vec{b}_{j+1} \end{bmatrix} = \begin{bmatrix} M1 & M2 \\ M3 & M4 \end{bmatrix} \begin{bmatrix} \vec{a}_j \\ \vec{b}_j \end{bmatrix}$$

VIEWGRAPH 2: RANGE DEPENDENT TEST

The environment for the first sequence of calculations is shown in viewgraph 2. The water depth varies slowly (note the vertical exaggeration) between 210 and 120 m over a range of 50 km. The water layer is downward refracting as can be seen from the sound speed profile. The underlying liquid sediment is homogeneous with the parameters indicated in the viewgraph. There is significant attenuation in the sediment.

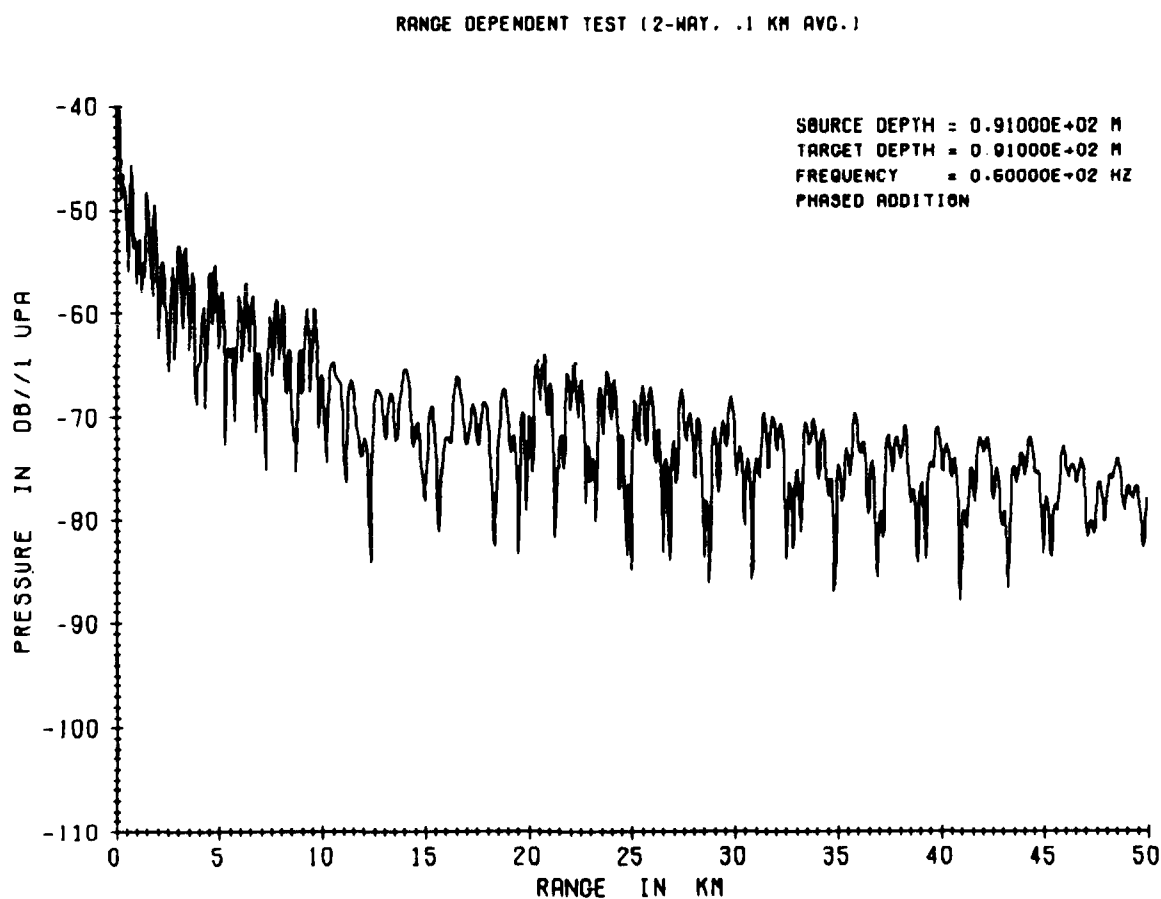
Range Dependent Test



VIEWGRAPH 2

VIEWGRAPH 3: COUPLE (50 Hz, 2-WAY)

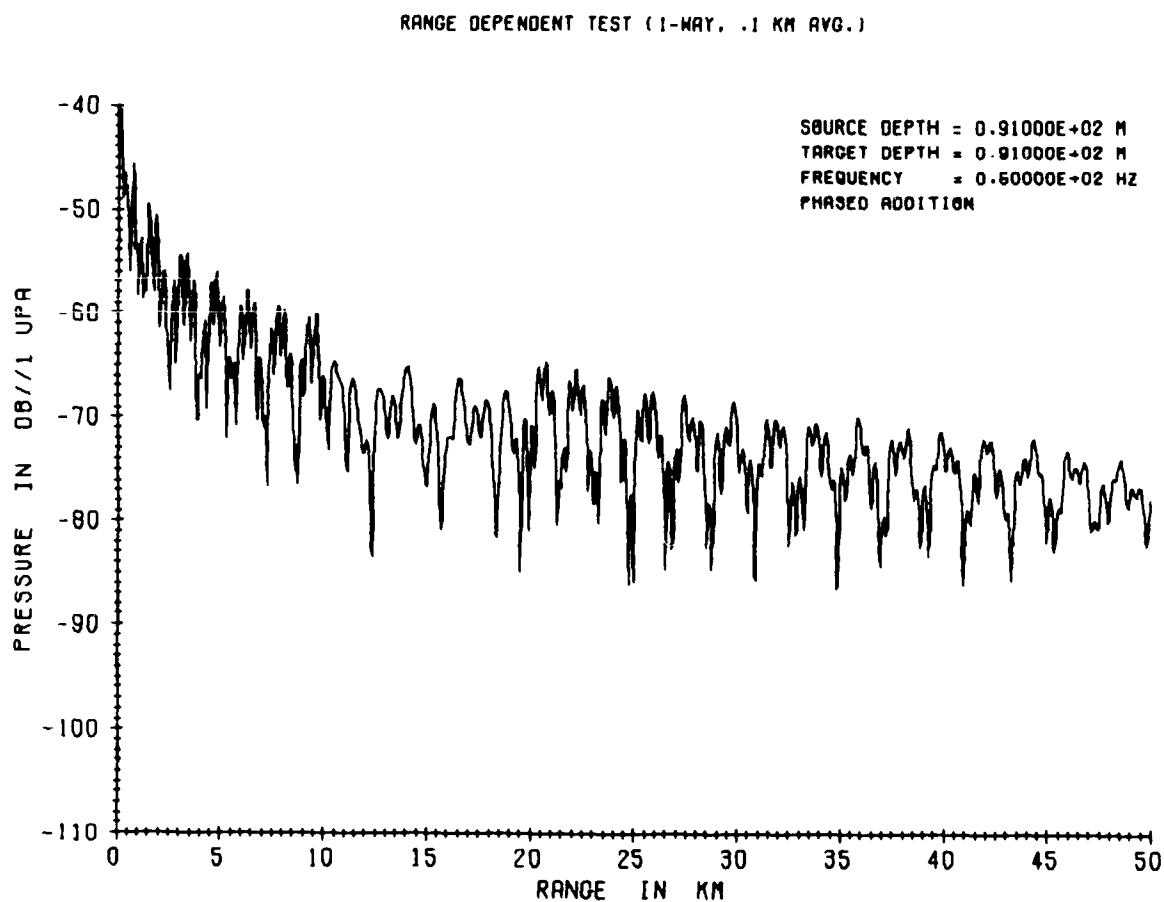
Viewgraph 3 shows the propagation loss for a 50 Hz source at 91 m and a receiver at 91 m. The propagation loss curve shows a pattern indicative of modal propagation with 5 - 7 modes contributing. There is a distinct spacing out of the pattern in the region over the notch in the bathymetry between 10 and 20 km. This is clearly a range dependent effect.



VIEWGRAPH 3

VIEWGRAPH 4: COUPLE (50 Hz, 1-WAY)

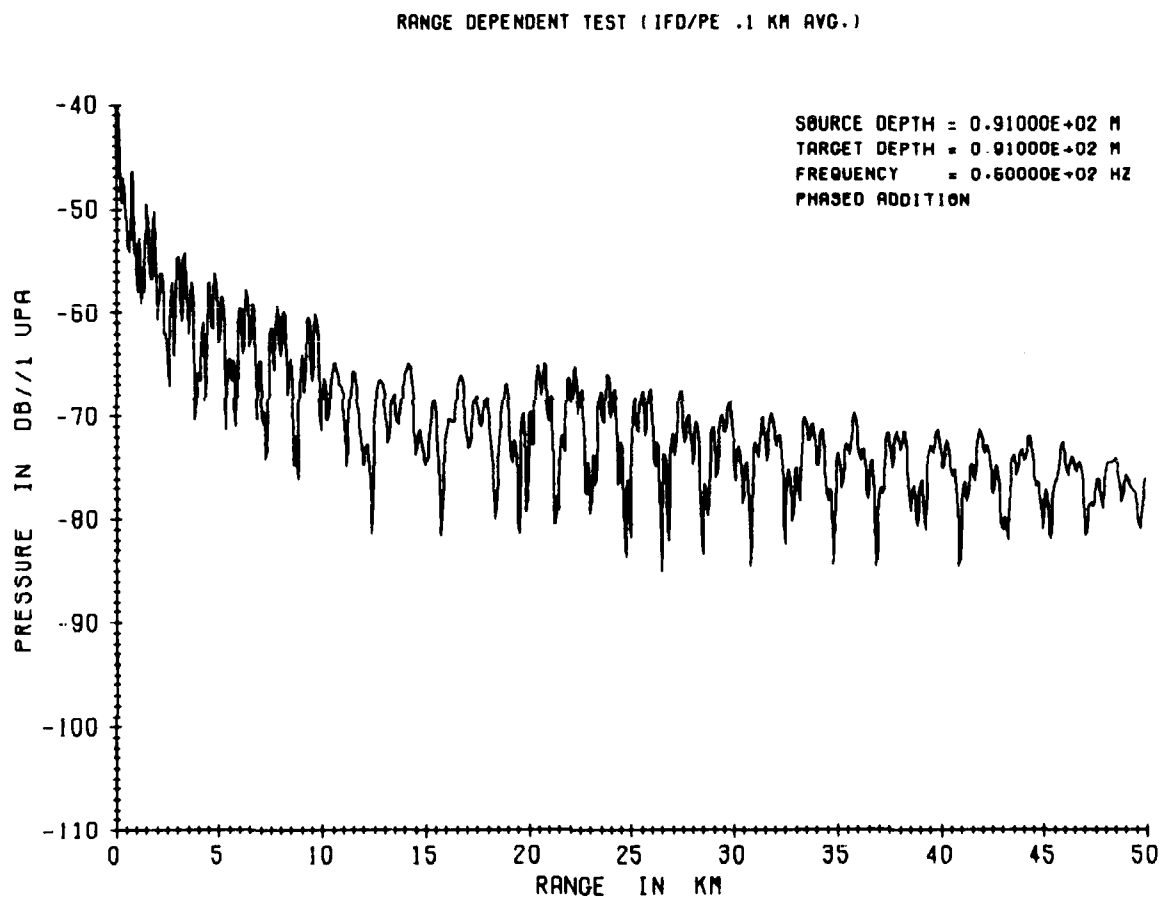
Viewgraph 4 is the same calculation but with no backscatter. We see from the comparison of the 1-way and 2-way COUPLE results that backscatter is not significant in this CW calculation. As a result, it should make a good test case for the parabolic equation (PE).



VIEWGRAPH 4

VIEWGRAPH 5: IFD/PE (50 Hz)

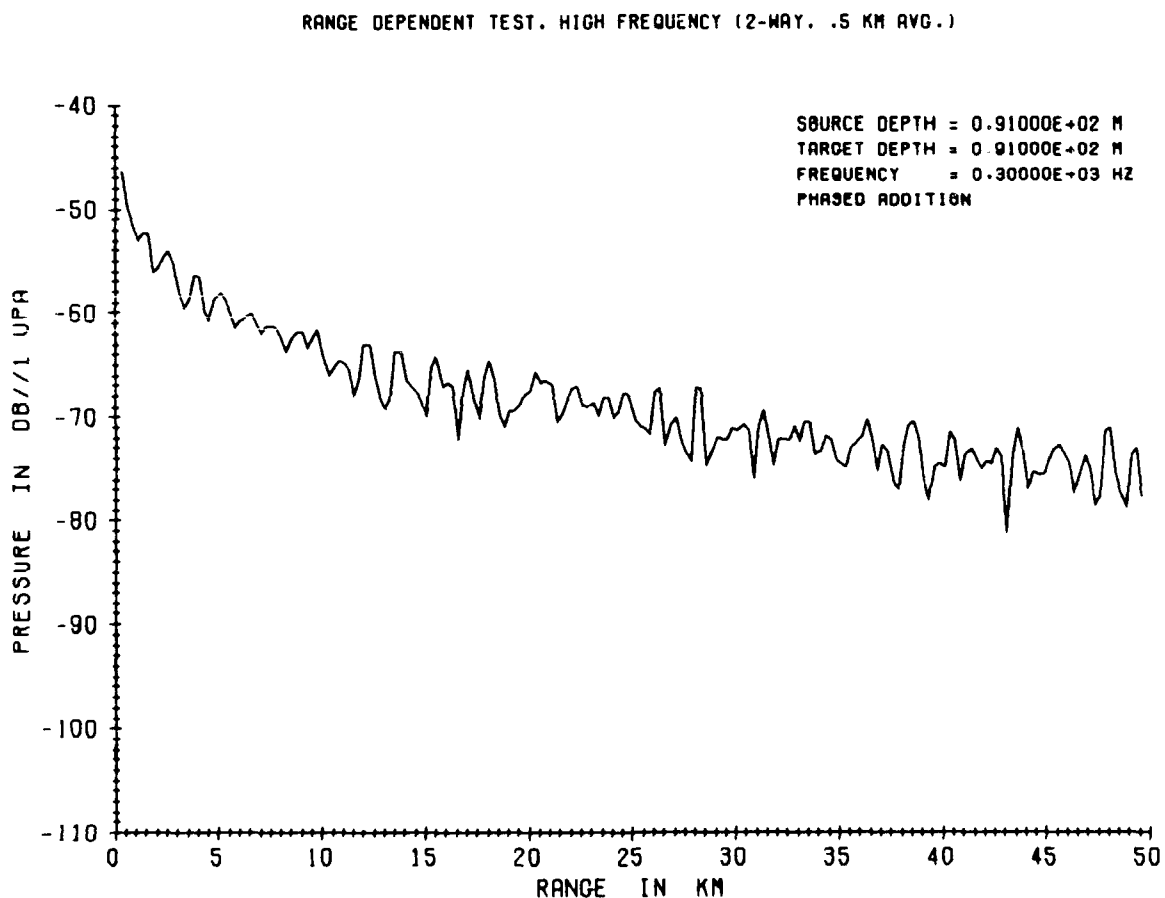
Viewgraph 5 is the IFD/PE result for the same test case. We have almost perfect agreement between COUPLE and IFD/PE. This is our most important point. If another range dependent model is applied to this case, it should produce the same pattern of phase and amplitude.



VIEWGRAPH 5

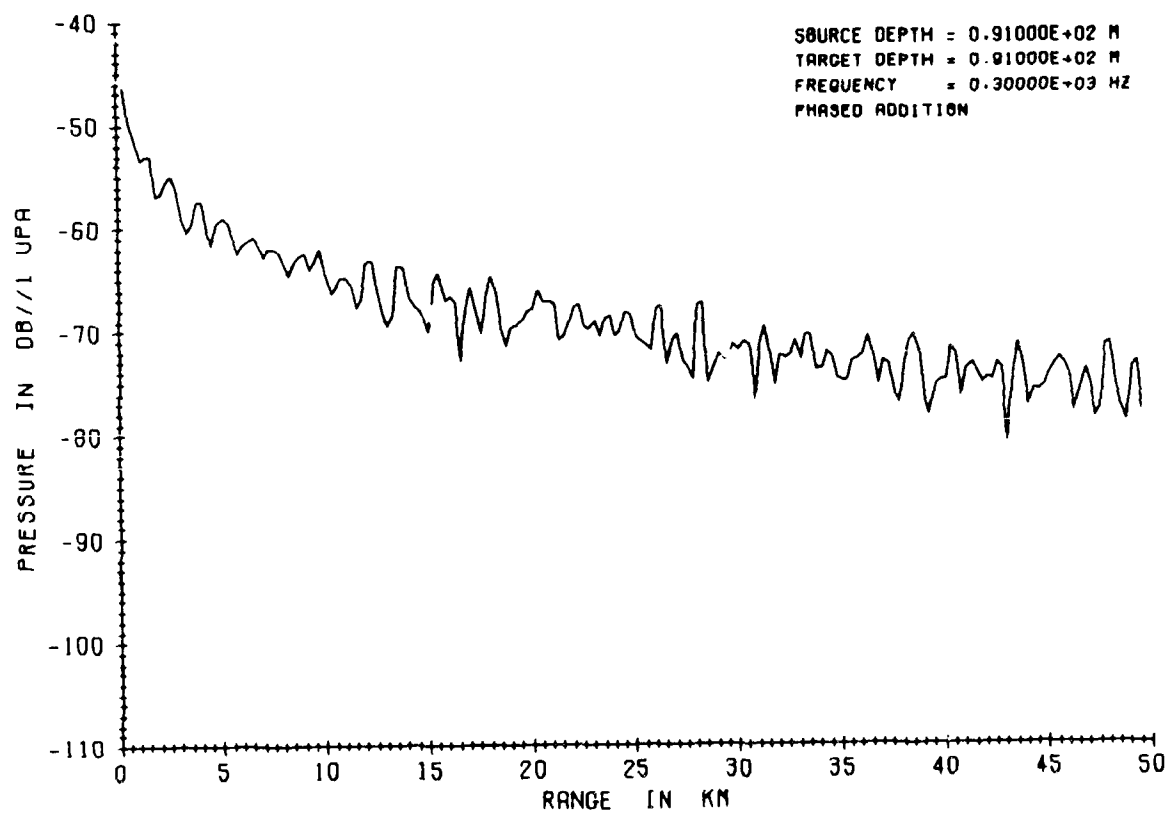
VIEWGRAPH 6: COUPLE (300 Hz, 2-WAY AND 1-WAY)

Viewgraphs 6 and 7 show the 2-way and 1-way COUPLE result at 300 Hz. Everything else is the same. The propagation loss has been averaged over 0.5 km to facilitate comparison. In this case, backscatter is not significant.



VIEWGRAPH 6

RANGE DEPENDENT TEST, HIGH FREQUENCY (1-WAY, .5 KM AVG.)

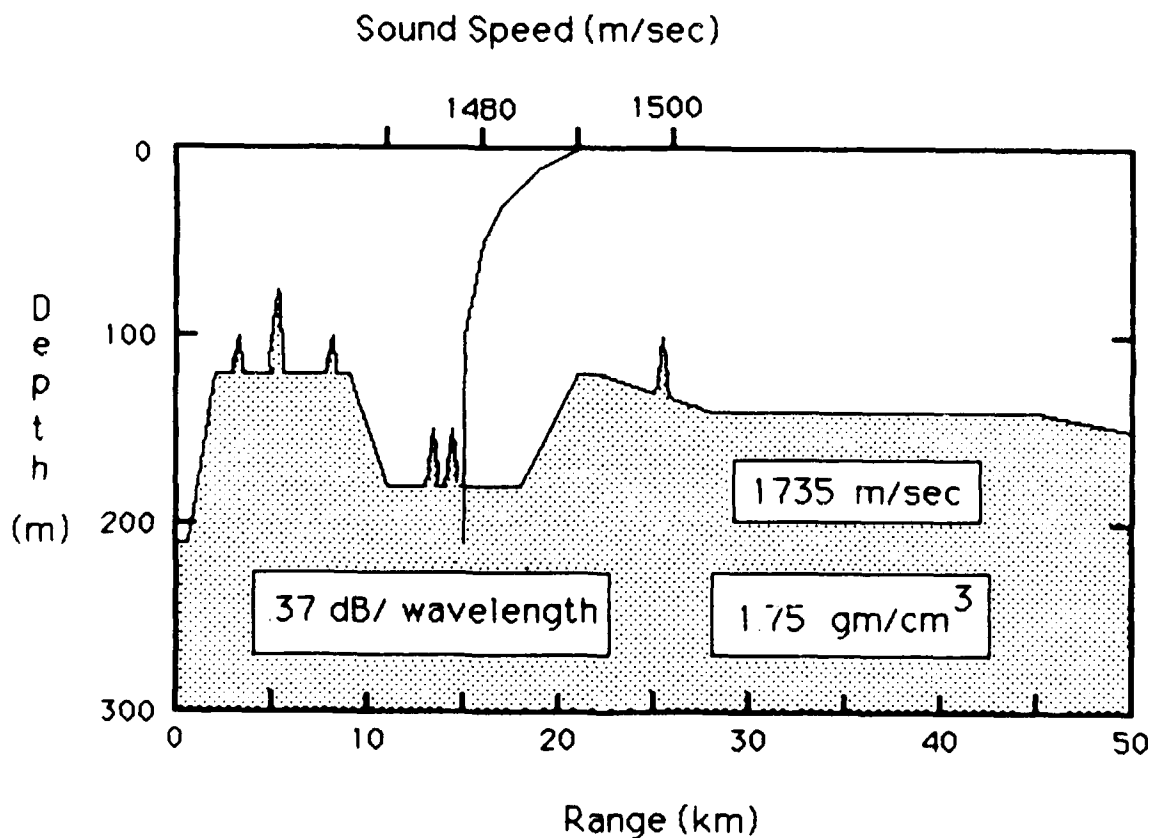


VIEWGRAPH 7

VIEWGRAPH 8: RANGE DEPENDENT TEST, SMALL SCALE ROUGHNESS

A second test case is shown in viewgraph 8. This is the same as the first test case except that some small scale roughness has been put in the bathymetry. These bathymetric changes are more rapid than the overall bathymetry. The vertical exaggeration makes them look like spires.

Range Dependent Test, Small Scale Roughness

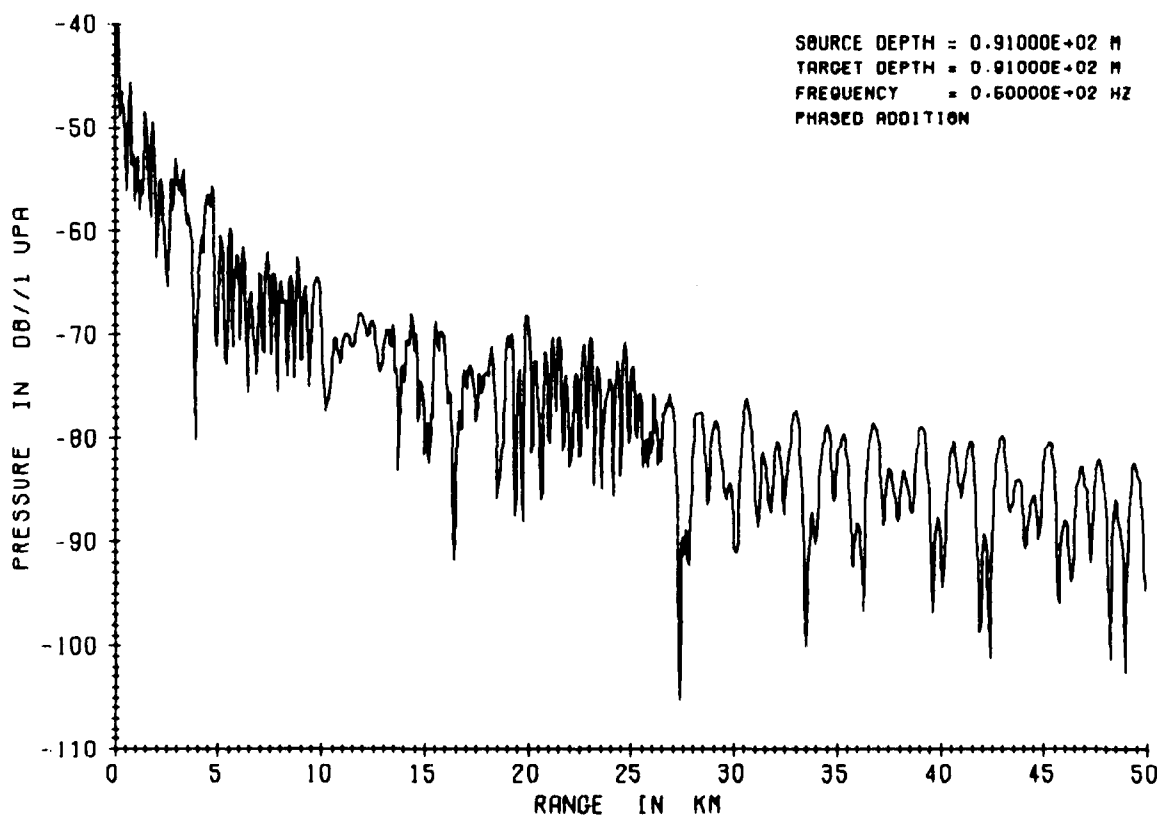


VIEWGRAPH 8

VIEWGRAPHS 9 AND 10: COUPLE (50 Hz, 2-WAY AND 1-WAY)

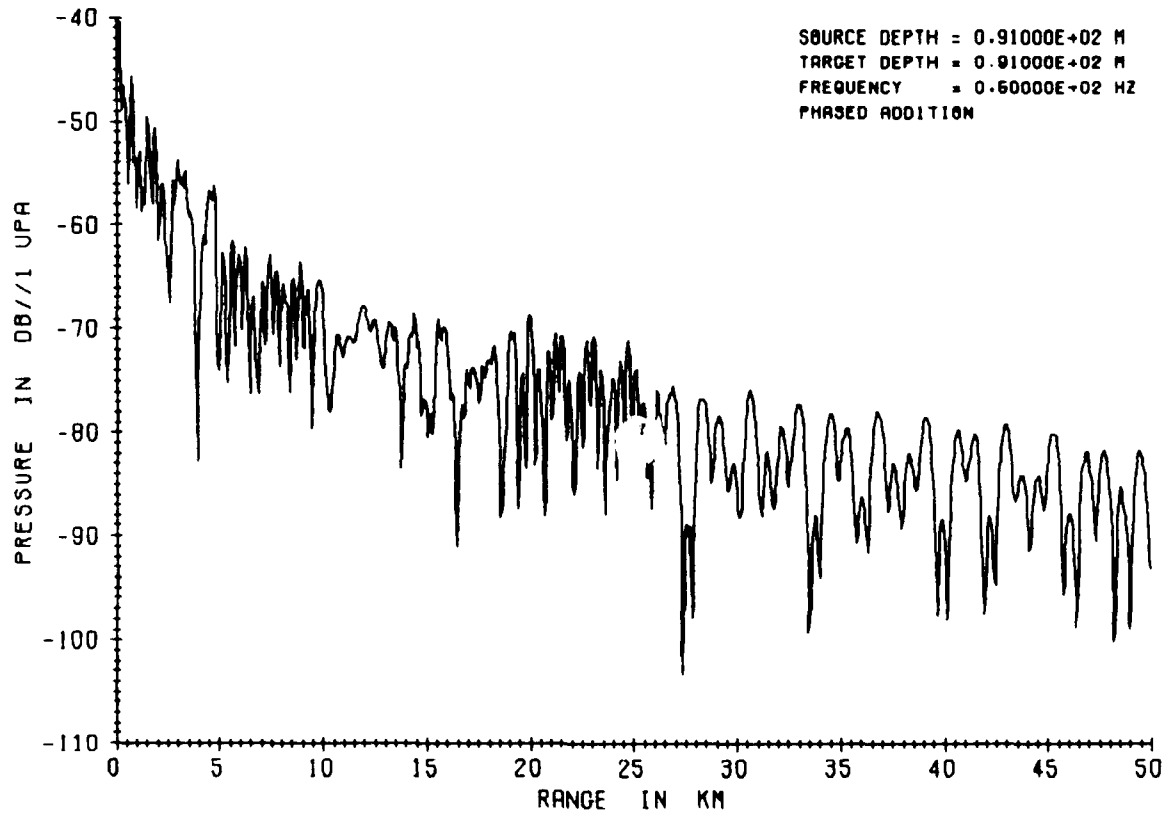
Viewgraphs 9 and 10 show the 2-way and 1-way COUPLE result at 50 Hz. The introduction of the small scale roughness has caused slight differences between the 1-way and 2-way results. The most significant effect is the higher loss caused by the roughness. This can be seen in comparison with the 2-way COUPLE result in viewgraph 3 where the roughness did not occur.

RANGE DEPENDENT TEST. SMALL SCALE ROUGHNESS (2-WAY, .1KM AVG.)



VIEWGRAPH 9

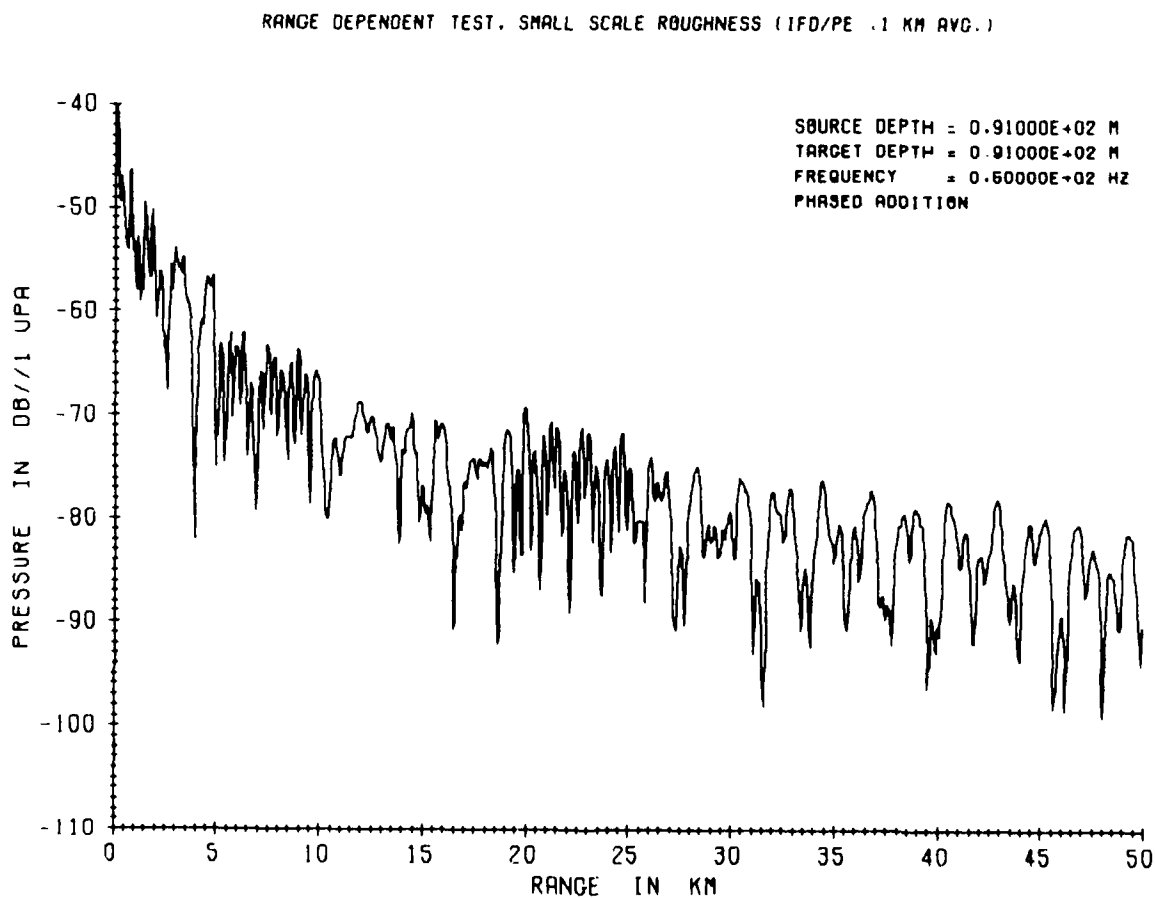
RANGE DEPENDENT TEST. SMALL SCALE ROUGHNESS (1-WAY. .1KM AVG.)



VIEWGRAPH 10

VIEWGRAPH 11: IFD/PE (50 Hz)

Viewgraph 11 is the IFD/PE result for the rough case. IFD/PE shows the same increased loss due to roughness. The comparison with COUPLE is not quite as good as in the case without roughness.



VIEWGRAPH 11

SUMMARY

The COUPLE model was applied in a range dependent shallow water environment. The COUPLE results were compared with IFD/PE results for the same problem. Both models provide comparable results. The COUPLE model provides for backscattered energy, but in this problem backscattered energy is insignificant. Further tests showed that including small scale roughness elements had more influence on propagation loss than any other single factor.

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